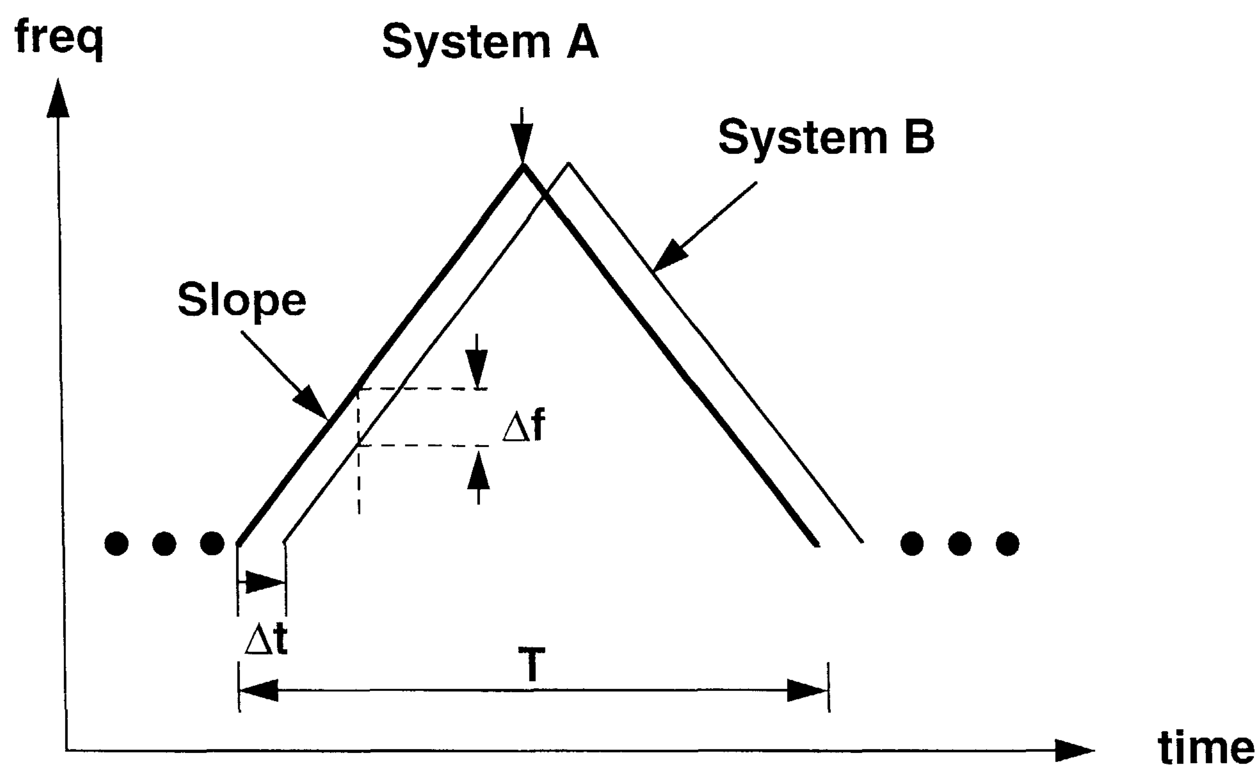
Like Systems Mutual Interference—First Order Analysis

- P_{FA}: Probability of false alarm due to mutual interference of two like systems
- P_{SYN}: Probability of synchronization of signal transmission of the two like systems
- P_{OVLP}: Probability of the RF frequencies of the two like systems overlapping each other—depends on manufacturing control
- P_{ANT}: Probability two antennas look at each other
- Since synchronization and RF overlap, and antenna boresighting are caused by independent processes, they are independent. Thus,

$$P_{FA} = P_{SYN} \cdot P_{OVLP} \cdot P_{ANT}$$

Mutual Interference: Synchronization Requirement



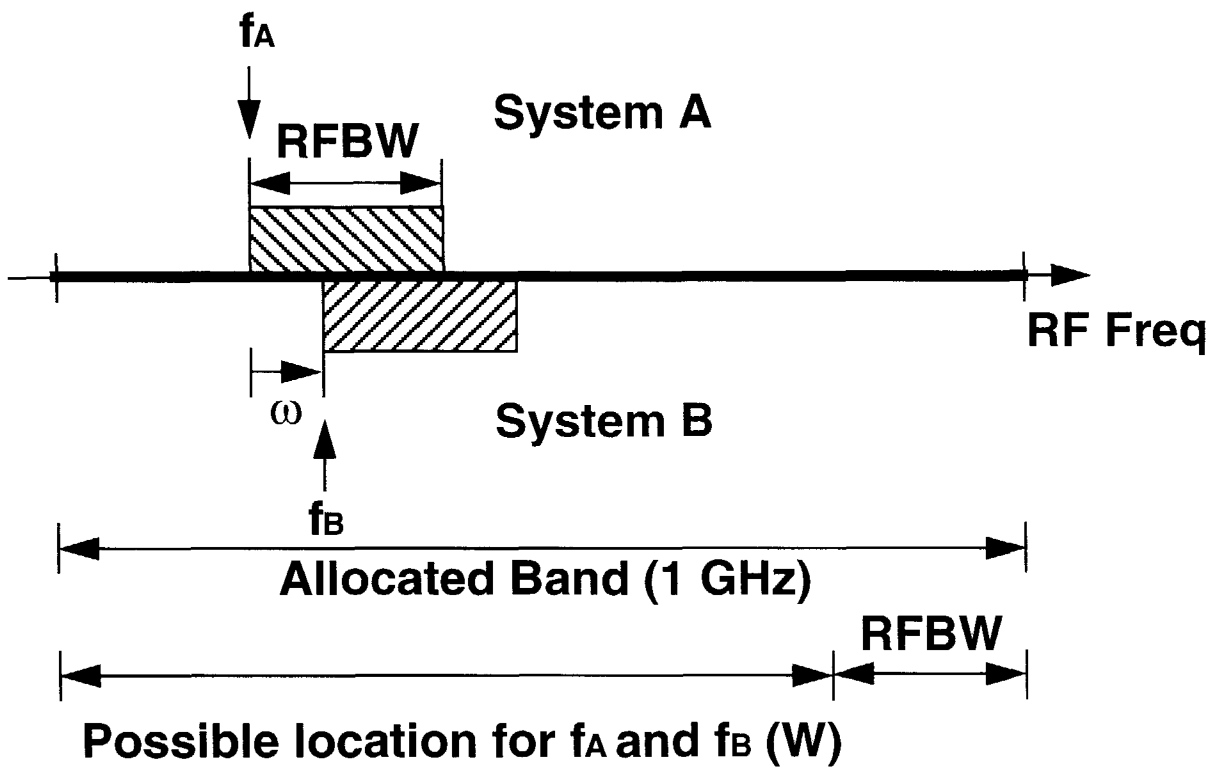
$$|\Delta f| \leq \mathrm{IFBW} \Rightarrow |\Delta t| \leq \frac{\mathrm{IFBW}}{\mathrm{SLOPE}}$$

Mutual Interference: Probability of Synchronization

- Waveform is repeated with period of T
- Assuming that the two systems have completely random start-up,

$$P_{SYN} = 2 \cdot \frac{\left(\frac{IFBW}{Slope}\right)}{T}$$

Mutual Interference: RF Overlap Requirement



$$-\text{IFBW} \leq \omega \equiv f_B - f_A \leq \text{IFBW}$$

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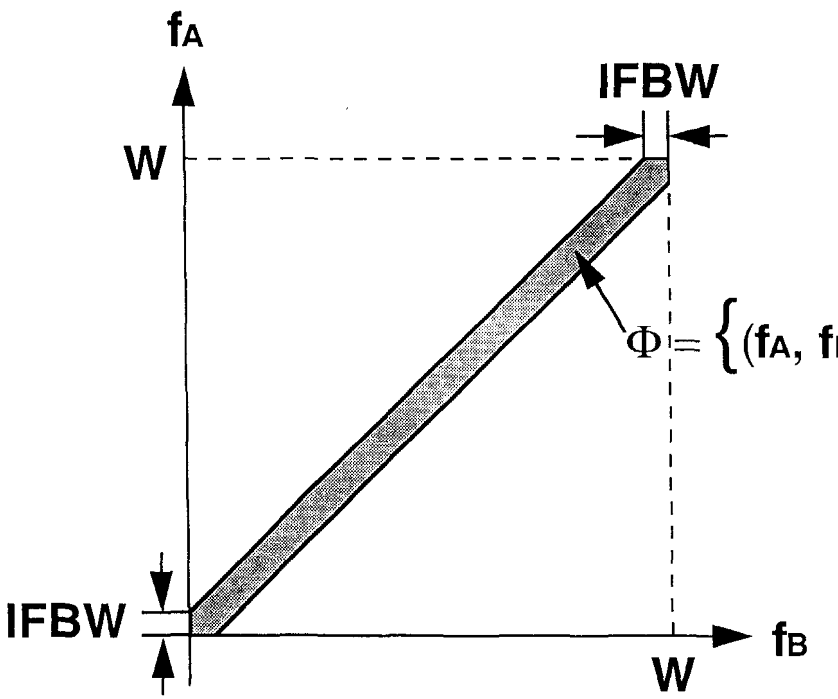
Mutual Interference: The Condition for RF Overlap



$$\Phi = \left\{ (f_A, f_B) : -\mathrm{IFBW} \le f_A - f_B \le \mathrm{IFBW} \right\}$$

Mutual Interference: Probability of RF Overlap

- Assuming that f_A and f_B are uniformly distributed over the $W \times W$ sample space, then

$$P_{OVLP} \approx \frac{2 \cdot IFBW}{W}; \quad IFBW << W$$

Mutual Interference: Probability of Antenna Boresighting

P_1 = Probability antenna #1 looking at antenna #2

P_2 = Probability antenna #2 looking at antenna #1

P_{DIR} = Probability both antennas moving same direction (CW or CCW) = 0.5

$$P_{ANT} = P_1 \cdot P_2 \cdot P_{DIR}$$

For our system, $P_1 = P_2 = 0.1$ for straight road, adjacent opposing lanes (worst case)

$$P_{ANT} = (0.1)(0.1)(0.5) = .005$$

Mutual Interference: False Alarm Rate

- For an automobile equipped with the GMHE radar, P_{FA} is the probability that a similar system will cause it to generate a false alarm
- Suppose one encounters n such (similar) systems every second
- P_{FAPH}: The probability that at least one false alarm is generated over a period of one hour is

$$P_{FAPH} = 1 - \left(1 - P_{FA}\right)^{3600\,N}$$

- For small P_{FAPH}, the false alarm rate (FAR), i.e., one false alarm per FAR hours:

$$FAR = \frac{1}{P_{FAPH}}$$

Mutual Interference: Calculated FAR Estimates Are Very Conservative

- Assumes antennas of interfering radars are looking directly at each other and this occurs once per second
  - Should not happen on divided highways
  - Could happen on roads with adjacent opposing lanes and no barrier
- "Target Selection" algorithm will eliminate alarms for targets not in path of radar car
- Assumes FM slopes are identical for every unit; not true due to manufacturing tolerances; differences in actual slopes significantly reduce probability of frequency overlap

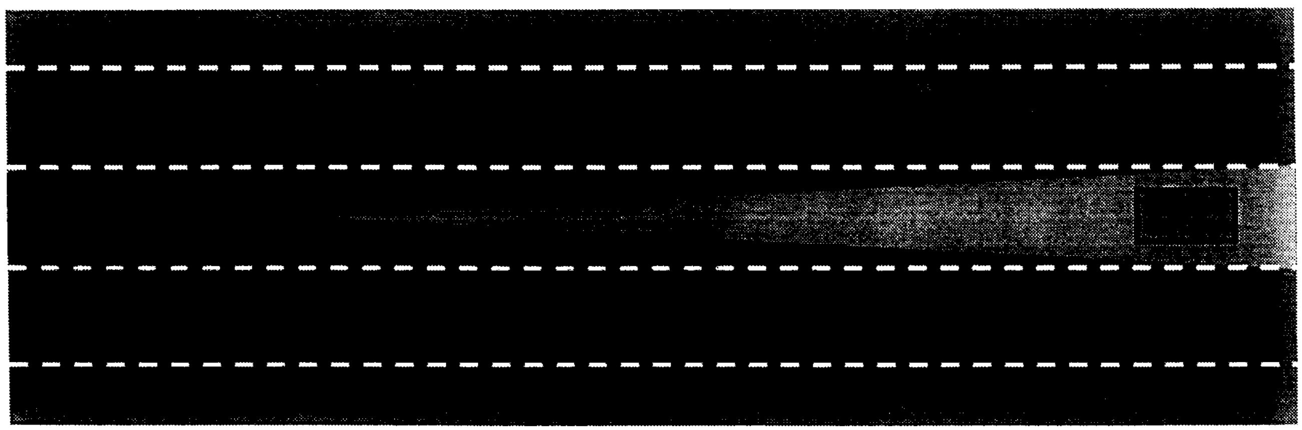
Technical Appendix B

Forward-Looking Radar Design Considerations

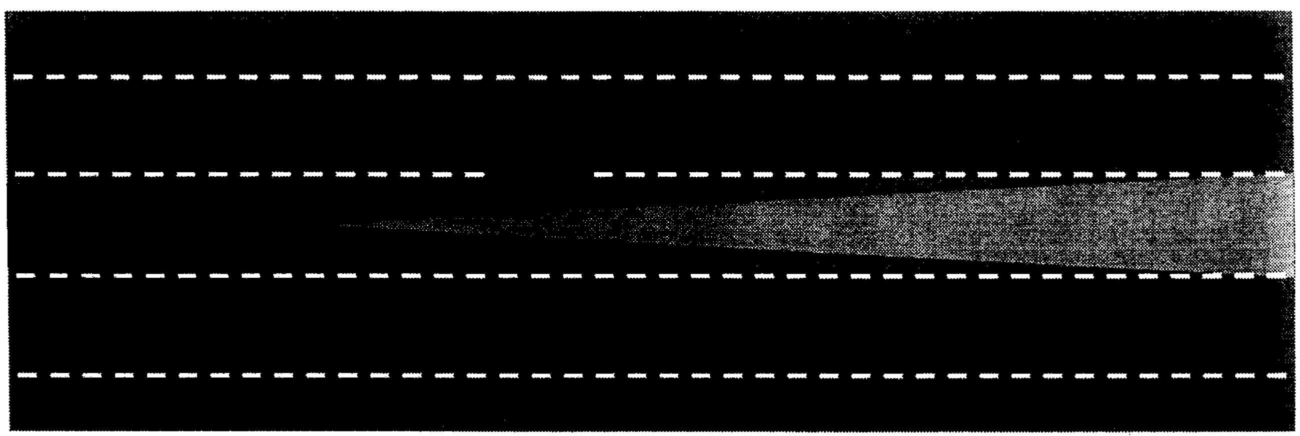
Radar Design Considerations:

Narrow Beam FOV Approach Detects a Target Vehicle in the Same Lane

= Vehicle = Vehicle causing alert



But a narrow beam will miss near range cut-ins



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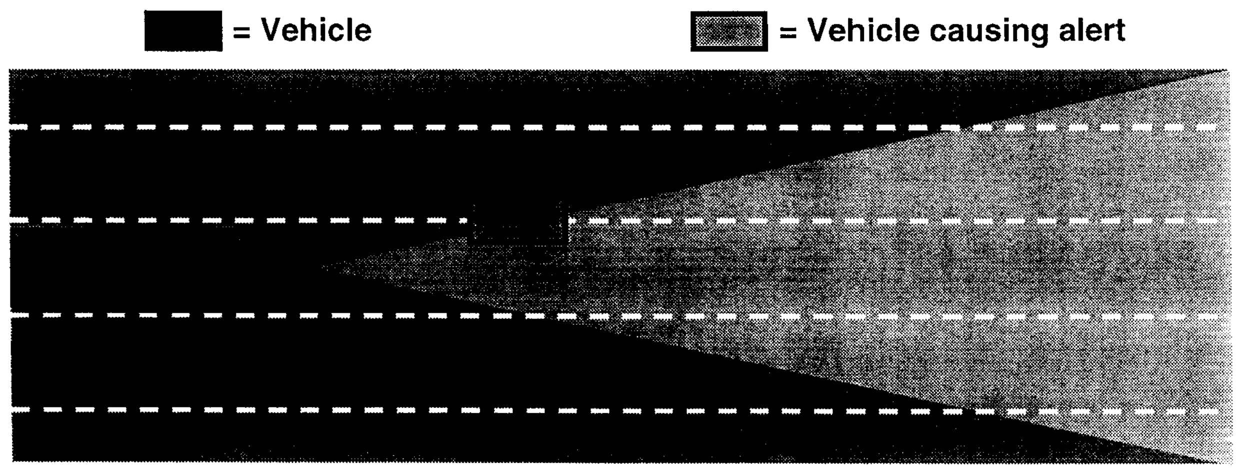
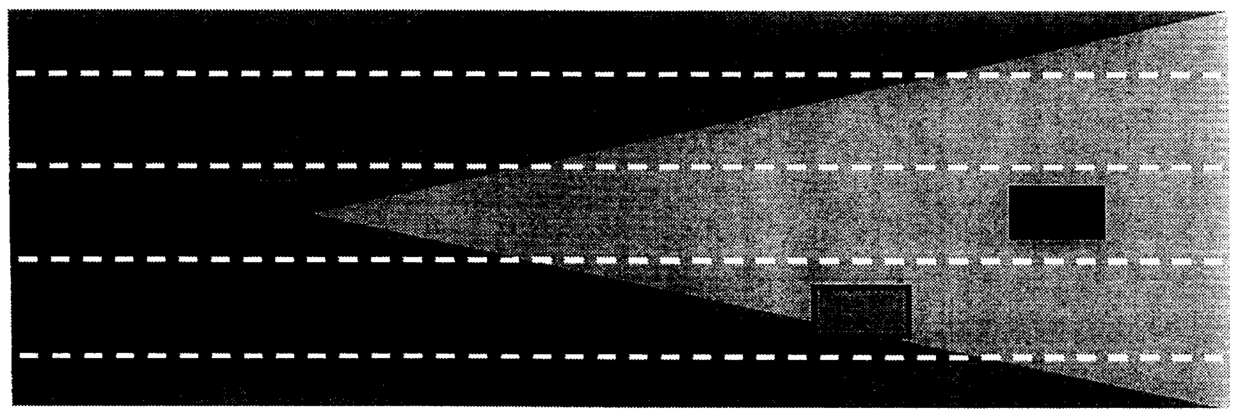
Radar Design Considerations:

Wide Beam FOV Approach Detects Near Range Cut-ins



But a wide beam can also cause false alarms from adjacent lane vehicles



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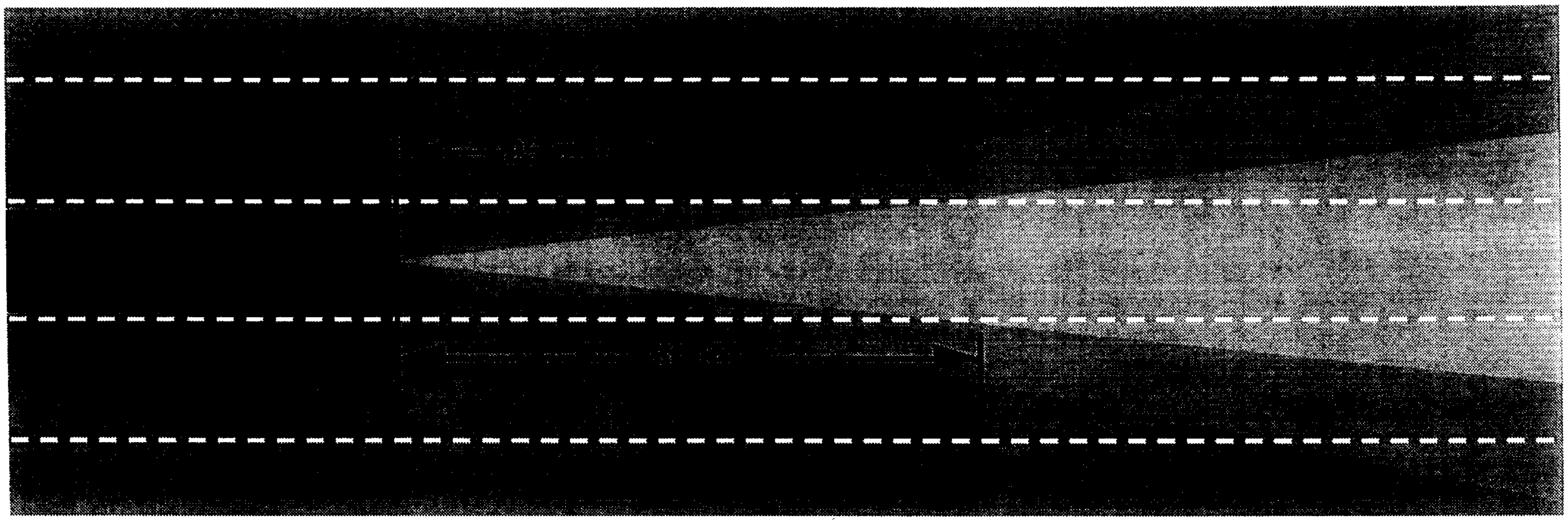
Radar Design Considerations:
A Compromise System with a Medium FOV Beam Has Limitations

= Target detection certain

= Target detection uncertain



- Adjacent lane vehicles detected beyond 50 meters
- Cut-ins closer than 25 meters are missed
- Uncertain performance from 25–50 meters

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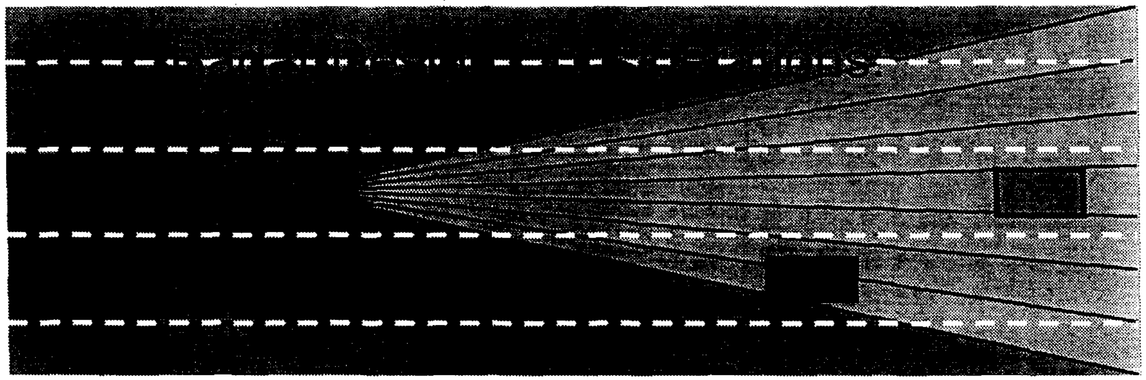
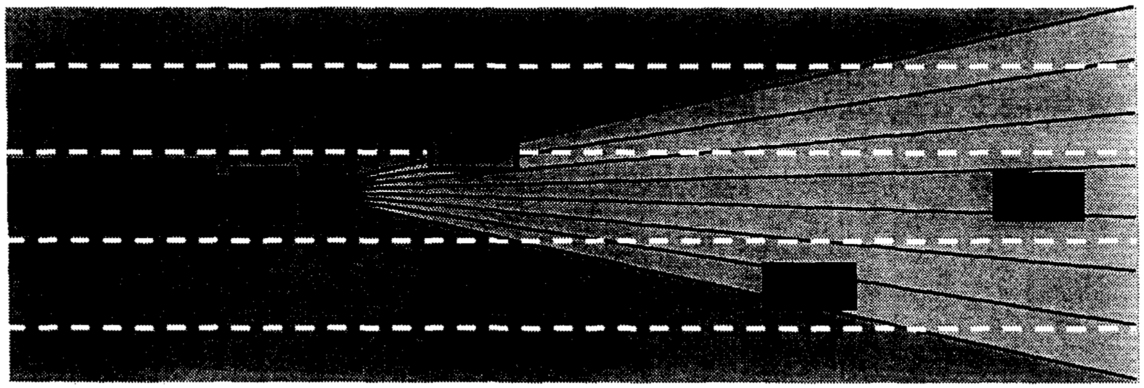
A Segmented FOV Will Not Give Adjacent Lane False Alarms

= Vehicle = Vehicle causing alert



- FOV is partitioned into sub-zones
- Targets are identified in these sub-zones



- Cut-ins are detected

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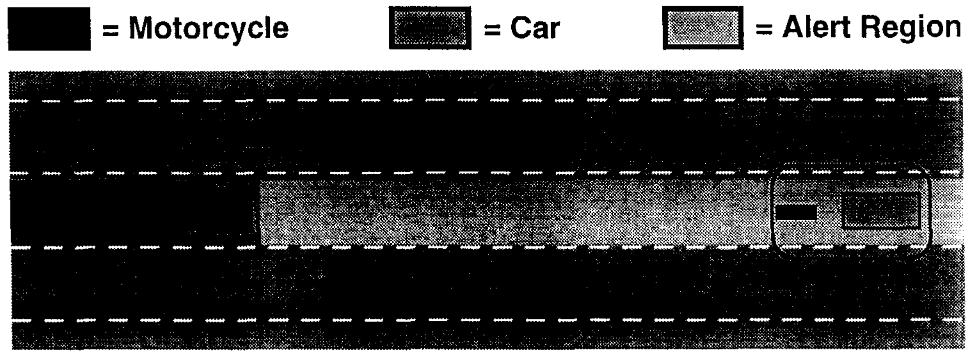
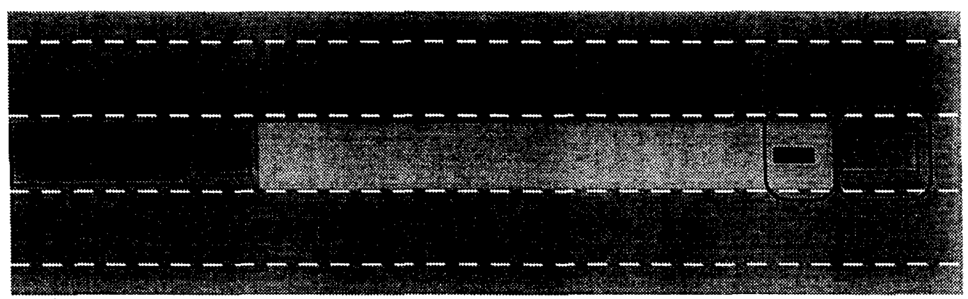
Radar Design Considerations:

Fine Range Resolution Is Essential



- Motorcycle and car seen as a single target
- Range measurements may vary, causing intermittent alerts
- Potential exists for collision with motorcycle



- Motorcycle and car are detected as separate targets
- Provides for steady range measurements
- Alert/no alert condition is stable

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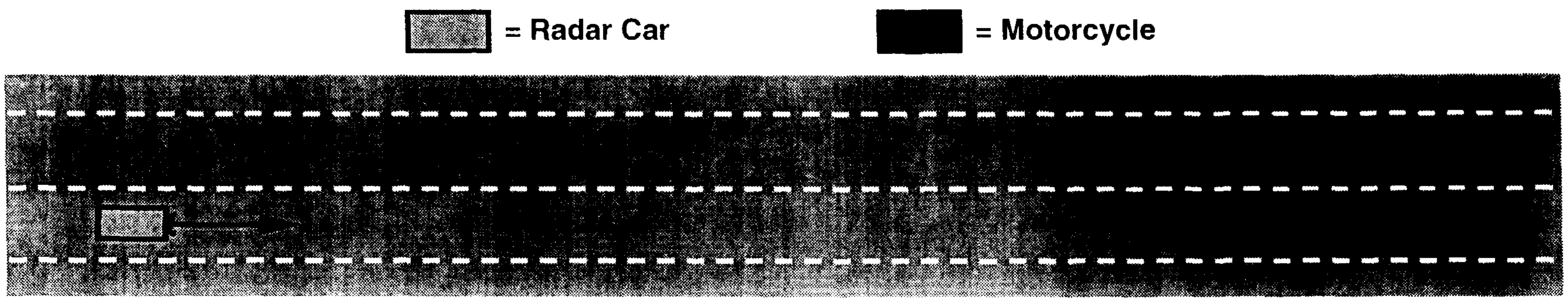
Radar Signal and Data Processing: AGC Algorithm Accommodates Large Differences in Target Radar Cross Section



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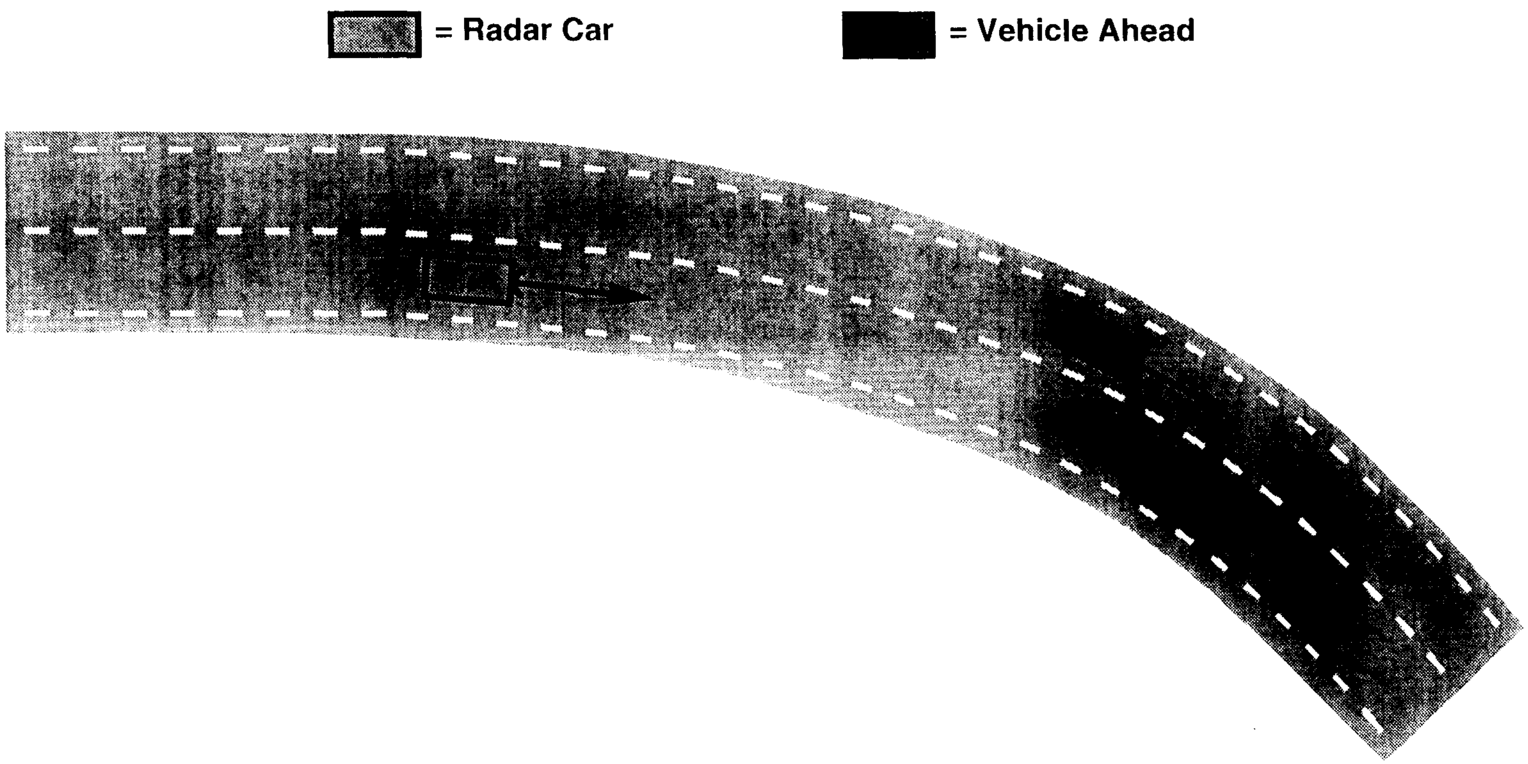
Radar Signal and Data Processing: Algorithm to Determine In-Path Target



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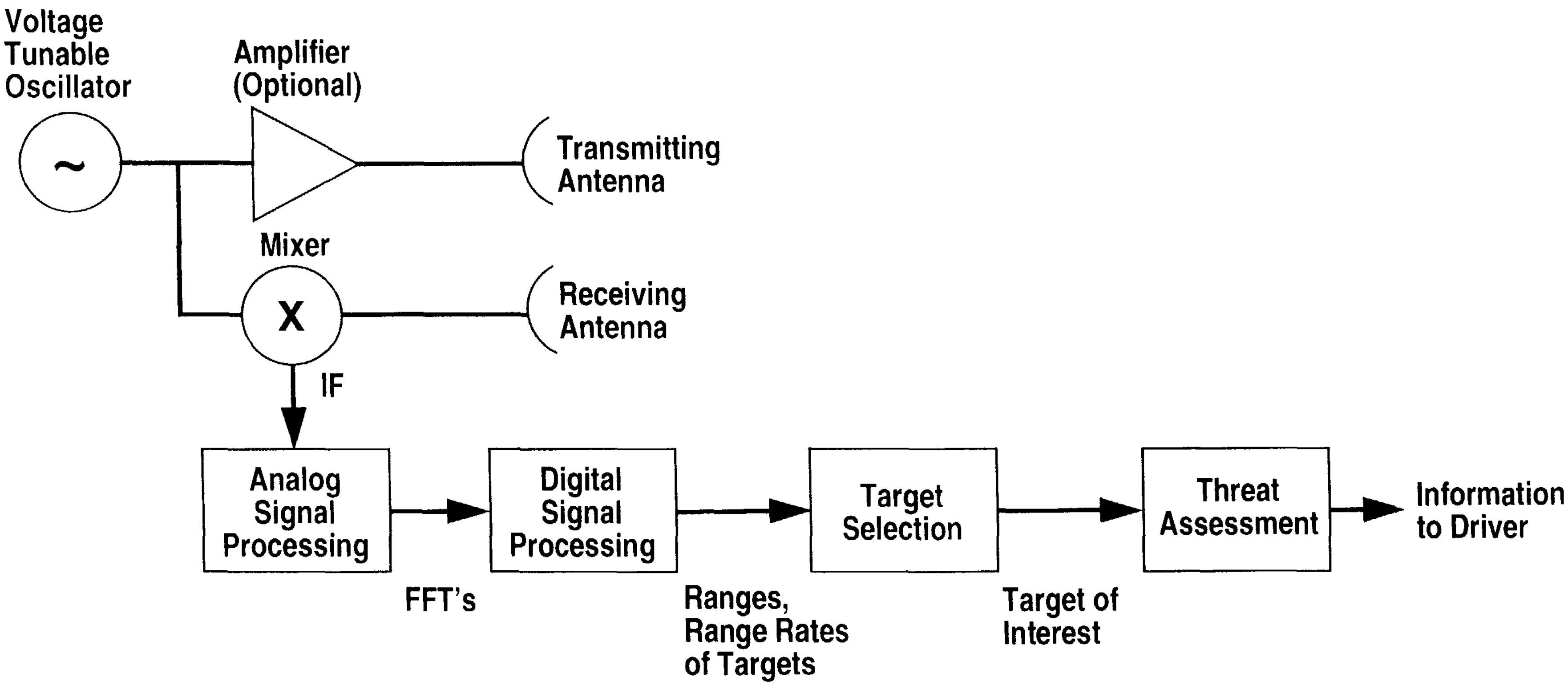
Technical Appendix C

FMCW Radar Overview

FMCW Radar Overview: Block Diagram



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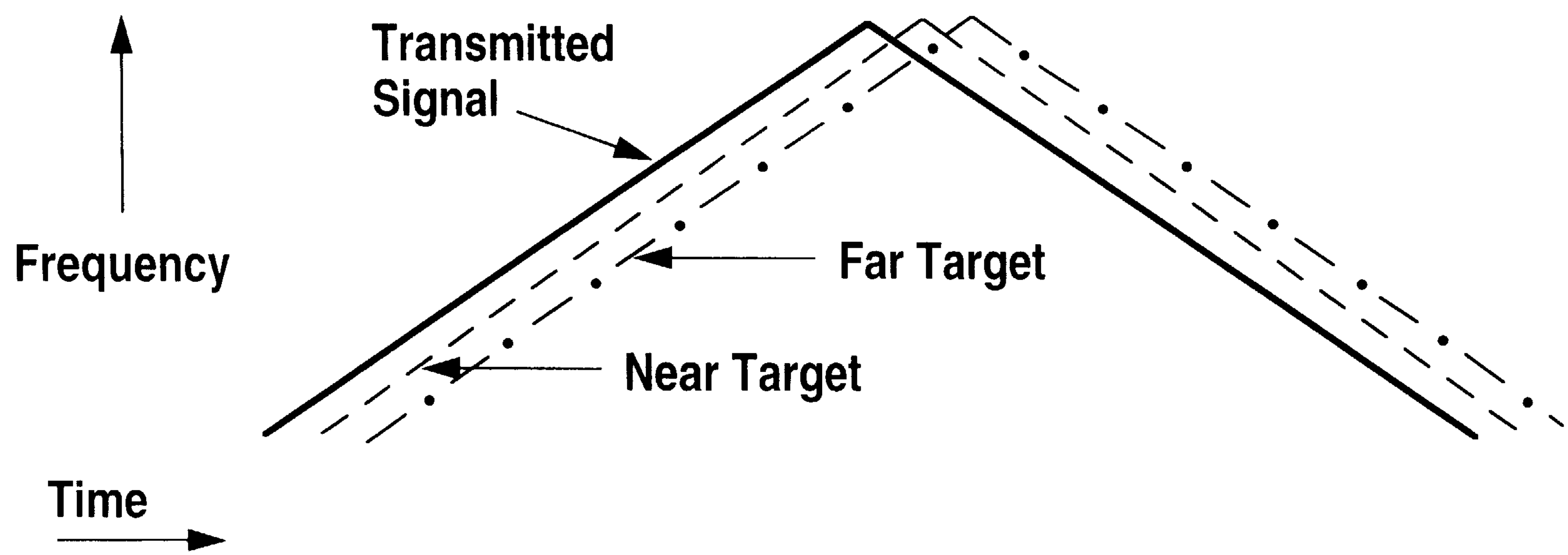
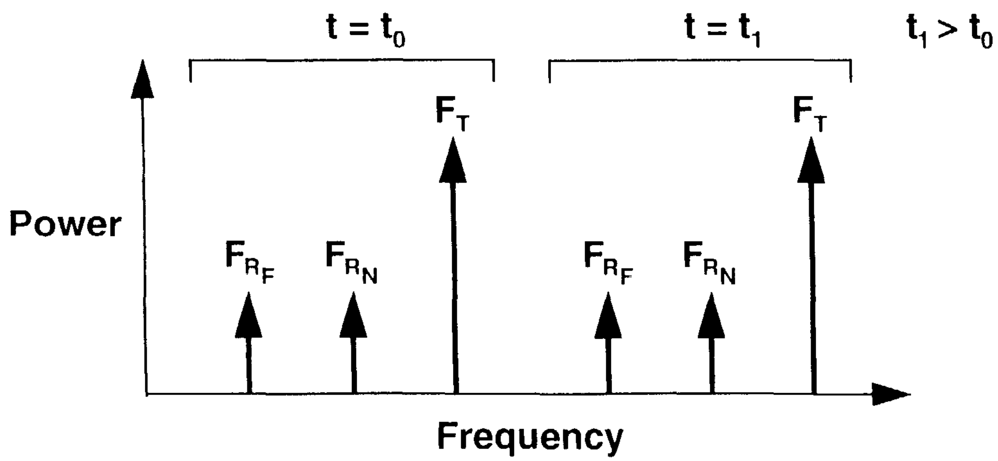
FMCW Radar Overview: Transmitted and Received Signals, Two Targets, Zero Doppler

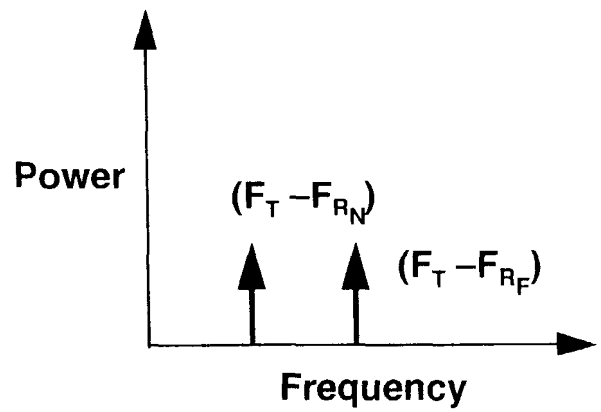


FMCW Radar Overview: Two Targets in the Frequency Domain

Mixer Input at Two Points in Time



Mixer Output



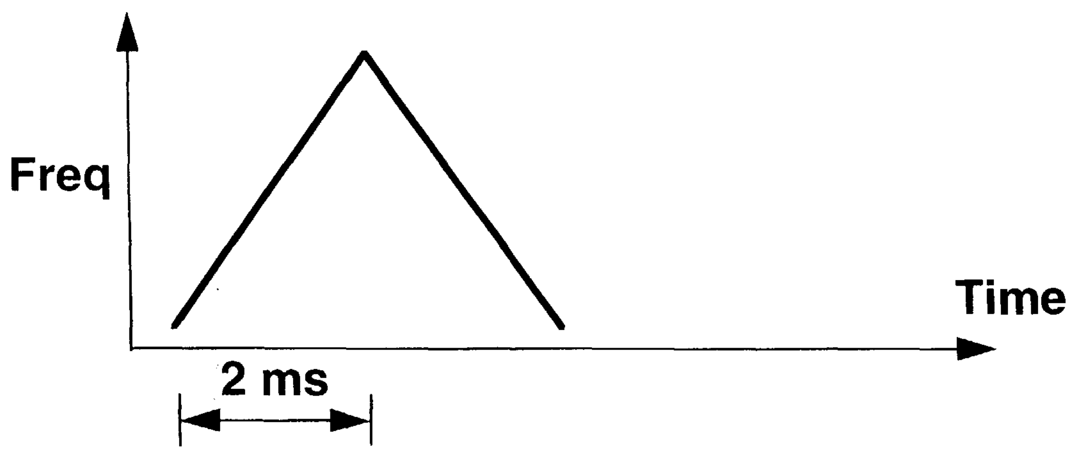
F_T = Transmitted carrier

F_{R_N} = Reflected signal from near target

F_{R_F} = Reflected signal from far target

FMCW Forward-Looking Radar: Principles of Operation (1)

- Modulation
  - Frequency modulated continuous wave (FMCW)
  - Positive and negative modulation slopes, 2 ms per slope



FMCW Forward-Looking Radar: Principles of Operation (2)

- Modulation (cont'd)
  - Radar returns are down-converted with transmitted signal in mixer
  - Frequency passed after down-conversion <100 KHz
- Antenna
  - Scans field-of-view (FOV)
  - Beamwidth $<3^\circ$

FMCW Forward-Looking Radar: Principles of Operation (3)

- Detection
  - Radar returns must exceed an amplitude threshold in order to be processed as a signal; threshold is adaptive with respect to average noise
  - Radar signal returns must exceed threshold on consecutive slopes in one scan direction before being recorded as a possible target

FMCW Forward-Looking Radar: Principles of Operation (4)

- Target of interest
  - Detected targets processed by “target selection” algorithm to determine which are in the path of radar car
  - Target of interest defined to be nearest in-path target